SUCCESSION PROCESSES OF A DYNAMIC RIPARIAN ECOSYSTEM: THE LOWER ALLIER RIVER (FRANCE)

MEIKE METZ
WWF-Institute of Floodplain Ecology, Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Josefstrasse 1,
D-76437 Rastatt, Germany

GREGORY EGGER
WWF-Institute of Floodplain Ecology, Institute of Geography and Geoecology, Karlsruhe Institute of Technology, Josefstrasse 1,
D-76437 Rastatt, Germany

MARÍA DÍAZ-REDONDO
School of Engineering. University of Lisbon. Avenida Rovisco Pais 1,
1049-001 Lisboa, Portugal

VIRGINIA GARÓFANO-GÓMEZ
Université Clermont Auvergne, Université Blaise Pascal, GEOLAB, BP 10448.
CNRS, UMR 6042, GEOLAB – Laboratoire de géographie physique et environnementale,
63057 Clermont-Ferrand, France

BORBÁLA HORTOBÁGYI
Université Clermont Auvergne, Université Blaise Pascal, GEOLAB, BP 10448.
CNRS, UMR 6042, GEOLAB – Laboratoire de géographie physique et environnementale,
63057 Clermont-Ferrand, France

JOHANNES STEIGER
Université Clermont Auvergne, Université Blaise Pascal, GEOLAB, BP 10448.
CNRS, UMR 6042, GEOLAB – Laboratoire de géographie physique et environnementale,
63057 Clermont-Ferrand, France

DOV CORENBLIT
Université Clermont Auvergne, Université Blaise Pascal, GEOLAB, BP 10448.
CNRS, UMR 6042, GEOLAB – Laboratoire de géographie physique et environnementale,
63057 Clermont-Ferrand, France

Riparian ecosystems are highly dynamic and are subject to hydrogeomorphological processes. In Europe, the lower Allier River (France) is one of the last remaining meandering rivers with laterally dynamic sections. For this study, we developed an original method to analyse the vegetation assemblages and succession processes. The analysis includes both spatial and temporal evolution in order to evaluate the shifting paradigm of habitat mosaic at the study site over a 60-year period. On the long-term, floods with low recurrence intervals tend to be important for small scale habitat changes, whereas major flood events lead to major habitat changes. Flood events did not change the overall habitat composition of the active tract but their spatial distribution. The lack of major hydrogeomorphological disturbance observed during the last two decades, however, led to a higher stability of floodplain ecotopes.

1 INTRODUCTION

Riparian ecosystems are intimately tied to physical, chemical, and biological processes varying in both space and time. Important physical processes are linked to hydrogeomorphological disturbances caused by floods, while the distribution of vegetation depends on both hydrogeomorphological processes and fluvial landscape patterns. To protect and manage highly dynamic riparian ecosystems, it is essential to understand the spatial-temporal distribution of vegetation and its interaction with natural disturbance regime. One of the most important characteristics of natural riparian ecosystems is their shifting habitat mosaic that fosters high biodiversity feature (Standford *et al.* [2]). In this sense, the Allier River is one of the last remaining meandering rivers with laterally

dynamic sections in Europe. Thus, it was suggested that the Allier River could be considered as a reference of natural fluvial processes and their interaction with riparian and floodplain vegetation for rivers in comparable hydrogeomorphic and bioclimatic contexts (Geerling *et al.* [1]).
The key question of this study is whether the shifting habitat mosaic concept (Standford *et al.* [2]) is applicable for the free-flowing and highly dynamic meandering section of the Allier River over the last sixty years. To answer this question, riparian and floodplain vegetation and succession processes were evaluated both at small patch (5x5 m grid) and habitat scales (1:10 000) in a 3.7 km river stretch and at an active tract of 326 ha.

2 METHODS

2.1 Study site

The study site is located in the lower course of the Allier River, 8 km south of the town of Moulins. It is a mobile meandering river section without major flow regulations. This river reach is characterized by a pluvial discharge regime with a mean annual discharge of 136 $m^3 s^{-1}$ (gauging station Moulins, 1968-2015). The 50-year flood discharge is 1500 $m^3 s^{-1}$ and the two-year flood discharge is 680 $m^3 s^{-1}$ (Table 1).

Table 1: Number of flood events of different recurrence intervals (hydrological data not available before 1968, winter 1968 missing in interval 1967-1978 = NA; Metz *et al.* [3]). Hydrological data provided by the Banque Hydro, France [http://www.hydro.eaufrance.fr/]

interval	**Q $m^3 s^{-1}$**	**8/1954-7/1960**	**8/1960-7/1967**	**8/1967-7/1978**	**8/1978-7/1983**	**8/1983-7/1985**	**8/1985-7/2000**	**8/2000-7/2005**	**8/2005-7/2010**	**8/2010-7/2014**
Years		6	7	11	5	2	15	5	5	4
>2x mean Q	**272**	NA	NA	55	26	7	48	14	17	13
2-yr flood	**680**	NA	NA	6	4	1	4	2	1	0
5-yr flood	**950**	NA	NA	4	0	1	1	0	0	0
10-yr flood	**1110**	NA	NA	0	2	0	2	0	0	0
20-yr flood	**1300**	NA	NA	0	1	0	1	1	0	0

2.2 Diachronic analysis

The historical evaluation of landscape mosaics is based on Geerling *et al.* [1] and un-published data (see Metz *et al.* [3]). Ecotope maps covering a time span of 60 years (1954, 1960, 1967, 1978, 1983, 1985, 2000, 2005, 2010 and 2014) were used. The classification of ecotopes was made according to classes defined by Geerling *et al.* [1]: water (channel & stillwaters), bare sediment (gravel, sand, silt/mud), pioneer vegetation, grassland vegetation (reed, forbs, grasslands), bush (willow shrub, cottonwood shrub, willow-cottonwood shrub, *Prunus/Crataegus* shrub) and forest (white willow forest, black cottonwood forest, willow-cottonwood forest, willow/cottonwood-oak-elm forest, oak-elm forest, oak-*Robinia* forest).

2.3 Succession processes

A grid (5x5m) with the ecotope information of all ten years was created in ArcGIS 10.3. Processes of ecotope change from one map to the subsequent one were defined based on the methodology used by Diaz *et al.* [4]:

a) Progression, prevailing trajectory towards vegetated ecotopes: initial (water bodies → bare sediment); colonization 1 (water bodies/bare sediment/pioneer → grassland & water bodies/bare sediment → pioneer); colonization 2 (water bodies/bare sediment/pioneer → bush); transition 1 (bare sediment/pioneer → bush/forest & grassland → bush/forest); transition 2 (bush → forest)
b) Retrogression implies the destruction of vegetation by lateral erosion and sediment deposition on point bars and within side channels. It has a prevailing backwards trajectory of ecotope change: channel-shift/erosion (any ecotope in the active tract → water body); initial/aggradation (any ecotope → bare sediment/pioneer); partly retrogression (forest → bush/grassland & bush → grassland); retrogression of cultivated land (cultivated land outside of the active tract → any ecotope/mainly water bodies)
c) Stable, areas that do not show any change over two time steps and stable agriculture
d) Anthropization, solely associated to human induced changes: cultivation.

3 RESULTS

3.1 Spatial distribution of ecotopes in diachronic series

The Allier River is characterized by constant displacement of its bed influencing the development of the riparian ecosystem. Figure 1 shows the distribution of ecotopes in each year. Since 1983, the amount of forest has been progressively increased, while grassland decreased until 2000 before increasing again. Pioneer species increased considerably between 1978 and 1983, returned to similar levels as 1978 in 1985 and then steadily increased to 2010. Bare sediment and forest ecotopes showed the greatest variability, with bare sediment decreasing from 1985 whilst forest was increasing from 1985. The amount bush increased gradually to 1985 before decreasing to 2010. The amount of water remained relatively stable over.

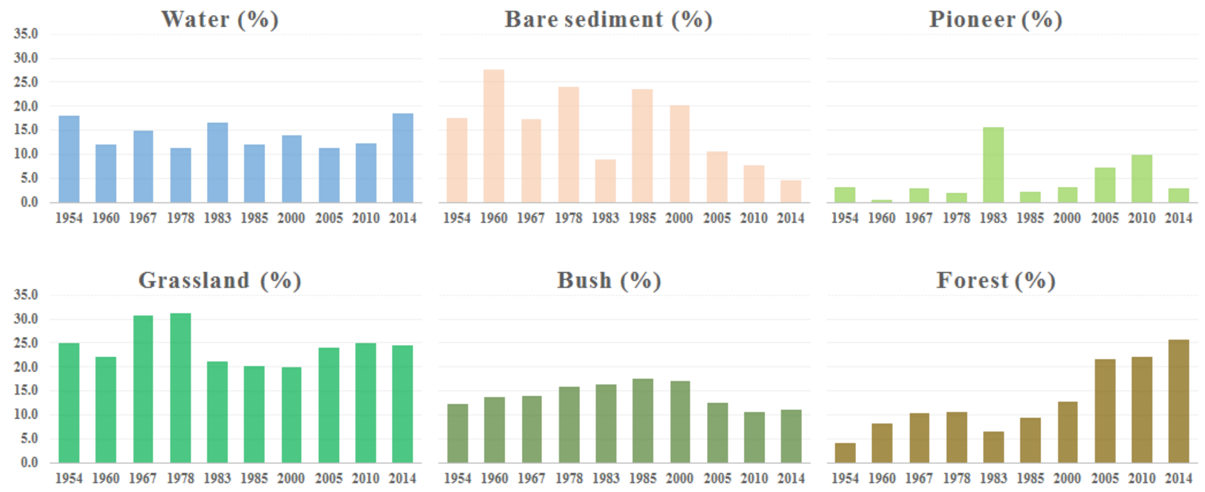

Figure 1. Percentage of each ecotope at all time steps (modified from Metz *et al.* [3]).

3.2 Succession processes

Table 2. Dominant succession processes of ecotope change (%) (Metz *et al.* [3]).

	Succession processes	8/1954 - 7/1960	8/1960 - 7/1967	8/1967 - 7/1978	8/1978 - 7/1983	8/1983 - 7/1985	8/1985 - 7/2000	8/2000 - 7/2005	8/2005 - 7/2010	8/2010 - 7/2014
Pro-gression	initial	11.1	4.3	6.9	2.6	4.8	5.1	3.3	2.5	1.3
	colonization 1	3.3	11.9	11.2	15.6	6.0	10.9	14.4	7.6	5.7
	colonization 2	1.9	1.6	1.2	1.6	0.6	3.0	4.1	0.9	0.5
	transition 1	6.0	3.3	6.7	5.9	7.7	7.2	5.6	1.4	7.3
	transition 2	3.4	2.5	1.6	1.6	4.3	3.4	7.3	0.9	3.7
	sum	25.7	23.7	27.7	27.3	23.3	29.6	34.7	13.2	18.5
Retro-gression	channel-shift/erosion	4.0	5.0	6.0	11.0	3.1	9.6	4.8	4.3	7.7
	initial aggradation	3.1	0.4	7.3	3.6	11.8	6.0	1.8	3.5	2.2
	partly retrogression	3.3	5.1	4.6	5.7	4.6	4.3	3.6	2.3	4.8
	retrogression of cultivated land	4.9	6.8	5.4	1.5	1.0	2.4	1.0	0.3	0.1
	sum	15.3	17.3	23.3	21.9	20.4	22.3	11.2	10.4	14.8
Stable	stable	43.0	49.3	44.1	36.1	41.0	34.9	41.2	63.7	54.1
	stable agriculture	14.8	9.2	4.4	3.5	13.7	12.9	12.2	12.7	12.6
	sum	57.8	58.5	48.5	39.6	54.7	47.8	53.4	76.4	66.7
Anthro-pization	cultivation	1.2	0.5	0.6	11.3	1.5	0.4	0.8	0.0	0.0
	total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Progression took place on point bars and islands with moist sediments, where are suitable for the establishment of pioneer woody vegetation. Between 1978 and 1983 both channel-shift and colonization 1 (beginning succession towards pioneer phase and/or grassland) were high. The period 2000-2005 also showed a high colonization rate as percentage of retrogression processes are low. During the entire 60-year period, stability was predominant, followed by progression; stable areas were more than twofold in comparison with areas that are dominated by retrogression processes. More specifically, stability of ecotopes dominated during the 2005-2010 (76.4%) and 2010-2014 (66.7%), intervals, whereas for the 1978-1983 and 1985-2000 periods, areas covered by ecotopes in succession (progression + retrogression) was 49% and 52% larger than areas occupied by stable ecotopes (Table 2).

4 DISCUSSION AND CONCLUSION

The ecological succession at the lower Allier River is driven by water availability and hydrogeomorphic disturbances (Metz *et al.* [3]). In the studied area, the riparian vegetation does not reach very old succession phases; the most mature phase observed is the Oak-elm forest at the highest elevations of the active tract. This suggests a highly dynamic past.

In general, the ecotope balance tends to be almost stable but it is strongly dependent on flood events. The observation of bare sediment areas depends on the water level at the time the aerial photo was taken. For instance, the 20-year flood in early 1982 caused a relevant channel shift and lateral erosion; as a consequence, the process colonization 1 affected 15% of the area of the active tract, whereas the large area of bare soil in 1978 (a quarter of the active tract) has to be taken into account (figure 1). These areas allow for the rapid establishment of pioneer species. High magnitude floods are capable of transporting large amounts of woody debris and sediment; likewise, they can also the only events responsible for the destruction of forest or changes in channel morphodynamics. A lack of flooding decelerates the modification of habitat mosaic because bare sediment does become less abundant within the riparian zone. Small flood events occur more often, but it is large flood events that produce the most dramatic and abrupt changes river channel change and habitat shift. Flow pulses below bankfull levels caused significant changes in habitat distribution, but without changing the overall habitat composition. This equilibrium is related to the balance between the capacity of the regular flood regime to erode meander outer bends and the resistance and resilience of pioneer species experiencing below bankfull floods (Metz et al. [3]).

This study observed a shifting habitat mosaic in a section of the Allier River over the last sixty years. Whereas the ecotope balance remains stable over the long term, habitats shift spatially within the active tract during short periods of 5-10 years. The lack of major hydrogeomorphological disturbance observed during the last two decades, however, led to a higher stability of floodplain ecotopes.

A future restructuration process of the river corridor, which destroys forest ecotopes and rejuvenates the fluvial landscape, will depend on geomorphologically effective high magnitude flood event.

REFERENCES

[1] Geerling G.W., Ragas A.M.J., Leuven R.S.E.W., van den Berg J.H., Breedveld M., Liefhebber D. and Smits A.J.M., “Succession and rejuvenation in floodplains along the River Allier (France)”, *Hydrobiologia*, Vol. 565, (2006), pp 71–86.

[2] Stanford J.A., Lorang M.S., & Hauer F.R. (2005). “The shifting habitat mosaic of river ecosystems“, *Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen*, 29, 123–136.

[3] Metz M., Egger G., Díaz-Redondo M., Garófano-Gómez V., Hortobágyi B., Geerling G., Steiger J. and Corenblit D., “Process-oriented ecological analysis of a dynamic riparian ecosystem: the lower river Allier (France)”, (in prep.).

[4] Díaz-Redondo M., Egger G., Marchamalo M., and Hohensinner S., ”Diachronic analysis of habitat structure and river-floodplain dynamics for the study of the reference condition and the ecological deficit of a large river system: the Upper Rhine River”, (in prep.).